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EFFECT OF BLACK POWDER COMBUSTION ON HIGH- AND LOW-PRESSURE IGNITER SYSTEMS

Kevin J. White
Hughes E. Holmes
John R. Kelso

November 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
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Large-caliber igniter systems have been evaluated using black powder lots which were manufactured with specific defects. The purpose of the program was to determine how the igniter system performance was affected by the black powder. At the same time, several conventional lots from two different black powder manufacturing companies were also tested in the igniters. Igniter action time was found to vary considerably depending on the lot used. Various other tests, including high-speed cinematography, have shown that the igniter performance

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) differences are related to combustion characteristics of black powder which vary from lot to lot. Slow-burning lots form large amounts of liquid droplets at the surface which then move into the flame above the surface. Fast lots burn with very little droplet formation. Particle size and the degree of mixing of the ingredients appear to be related to the combustion properties. However, more factors are involved and are currently under study. Examination of low-pressure igniter performance indicates that there are slow and rapid gas generation rates. The transition from the slow to the rapid rate takes place at low pressure.

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I. INTRODUCTION

The purpose of this work is to clarify the role of black powder combustion on the functioning of several large-caliber igniter systems. In particular, we are interested in learning what black powder manufacturing variables affect the burning of black powder and, subsequently, the functioning characteristics of igniter systems. The motivation for this investigation came from two areas. Because of a shortage of domestic supplies, the Army has constructed a black powder production facility employing a new jet-mill, continuous process. There is some concern about the ballistic quality of this black powder. Moreover, for safety considerations, this facility is to be remotely operated with only TV monitoring at specified locations. Production is to be carried out on a continuous basis with only spot checking of the final black powder. It is possible that deviations from standard production could take place. It would be desirable to know how these production differences would affect black powder performance in weapons systems. To this end, a number of special deviant lots were manufactured in the pilot jet-mill facility which had specific deviations intentionally introduced into the black powder. These are described in Table I. The ultimate objective of the program is to discover how these lots would affect the performance of Army weapons systems. This would be a help in determining black powder specifications. Since the number of weapon test firings required for such a program would be very large, it was felt that testing the performance of the igniter components themselves would be a useful screening technique.

A second motivation for this program came about from a hangfire that occurred with the M203 charge used in the 155-mm howitzer. The origin of this problem was traced back to the igniter and to a specific lot of black powder used in these charges. As a consequence, the following questions should be addressed. What is the lot-to-lot variation in black powder combustion? How does this variation affect igniter performance? How does this affect the performance of the M203 charge?

Three igniter systems were chosen which have important applications in Army weapon systems. All of them use Class 1 black powder[1]. The M28B2 (19.4 g) is a high-pressure bayonet type primer which is used in the 105-mm howitzer and in the 90-mm gun. The M203 charge igniter system contains a combination basepad (28 g) and centercore system (113 g). The M203 top-zone bagged charge is used in the 155-mm howitzer. This igniter is a relatively low-pressure system. The M2 charge igniter employs a basepad (142 g) and is used on the base-ignited, middle-zone charge in the 8-in howitzer. The same igniter is used in the M1 charge. It was believed that testing these igniter systems incorporating deviant lots of black powder should help in determining which are the most

[1] *J. C. Allen, "Concept Scope of Work for MM&TE Project 5764303, Acceptance of Continuously Produced Black Powder," Picatinny Arsenal Report No. SARPA-QA-X-010, November 1975.*

important production parameters with respect to ballistic performance. The following sections will outline the results of test firings using these igniters along with some other non-ballistic tests on the black powder lots. This work was supported in part by MM & TE Project 5764303, "Acceptance of Continuously Produced Black Powder"[1].

TABLE 1. DESCRIPTION OF DEVIANT LOTS OF BLACK POWDER

LOT 1 - High KNO_3 (KNO_3 - 78.01%, C - 11.95%, S - 8.50%)

LOT 2 - Low KNO_3 (KNO_3 - 73%, C - 16.3%, S - 10.4%)

LOT 3 - Poor agglomeration (poor blending homogeneity)-mechanical blending of jet mill ingredients instead of air blending

LOT 4 - High density powder (1.80 gm/cc)

LOT 5 - Low density powder (1.67 gm/cc)

LOT 6 - Non-standard glaze, n.s.g. (0.2% graphite instead of 0.1%)

LOT 7* - Charcoal with high carbon content (79.7%)

LOT 8* - Charcoal with low carbon content (61.6%)

LOT 9 - Large particle-size ingredient (jet mill product), average greater than 25 μm leaving jet mill

LOT 10 - Small particle-size ingredient (jet mill product) average 10 μm leaving jet mill

LOT 11 - GOE-75-44, green grain glazed with non-specification Dixon graphite (high ash content)

LOT 12 - GOE-75-44 (KNO_3 - 74.05%, C - 15.38%, S - 10.18%).

* Percent fixed carbon used in Lots 1-6, 9, and 10 was 73.8%. All percentages based on an ash-free and moisture-free basis. Details of the composition are given in the Appendix.

Several facts should be pointed out in comparing Table 1 with the Appendix. Lot 4 does not have the highest density (Lot 1 - 1.86 g/cm^3) nor does Lot 5 have the lowest density (Lot 10 - 1.63 g/cm^3). Secondly, the range of "high" and "low" carbon content is not wide. Rose[2] has reported charcoal analyses of between 82 and 91% fixed carbon. Hintze[3] has also reported values from 60.4 to 94.5% fixed carbon. In this latter instance it is not clear whether these numbers were or were not based on an ash-free and moisture-free basis.

Two other tasks were carried out on the deviant lots. Closed chamber evaluation was performed at the Large Caliber Weapon Systems Laboratory (LCWSL), ARRADCOM, Dover, NJ, by Shulman[4]. At the Princeton Combustion Research Laboratories[5] (PCRL), a ballistic test apparatus was designed which was used to measure the flamespread characteristics of black powder. Essentially this device consisted of a long metal tube with a series of slotted holes along the side. The idea was to simulate the performance of a high-pressure igniter but in a more controlled manner and to measure the flamespread rate which is believed to be a very important parameter for igniter systems. Results of these two tests will be mentioned when they are related to igniter functioning tests. Further experimental details of the tests performed in this report are given in Reference 6. Lot 11 is not in the same category as Lots 1-10 since it was manufactured by the conventional wheel-mill process.

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[2] *J. E. Rose, "Investigation on Black Powder and Charcoal," IHTR-433, Naval Ordnance Station, Indian Head, MD, September 1975.*

[3] *W. Hintze, "Einfluss des Kohlenstoffgehaltes der Holzkohle auf die Schwarzpulvereigenschaften" Explosivstoffe, 2, 41-48 (1968).*

[4] *L. Shulman, private communication, LCWSL, ARRADCOM, Dover, NJ, May 1978.*

5(a) *N. A. Messina, L. S. Ingram, M. Summerfield, "Black Powder Quality Assurance Flamespread Tester," Princeton Combustion Research Laboratories Report PCRL-TR-78-101, December 1978.*

5(b) *N. A. Messina, L. S. Ingram, M. Summerfield and J. C. Allen, "Flamespread Propagation Rates of Various Black Powders Using the PCRL-Flamespread Tester," Seventh International Pyrotechnics Seminar, Vol. 1, 388-407, July 1980.*

[6] *K. J. White, R. A. Hartman, I. W. May, J. R. Kelso, "Experimental Investigation of Ignition Train Systems for Bagged Charges," 14th JANNAF Combustion Meeting, Colorado Springs, CO, CPIA Publication No. 292, p. 117, August 1977.*

II. IGNITER FUNCTIONING TESTS

A. High-Pressure Bayonet Primer - M28B2

The M28B2 is a high-pressure bayonet-type primer used in the 105-mm howitzer. An example is shown in Figure 1. Earlier observations of primer firings have shown that the functioning of the primer is sensitive to orientation. Since most howitzer firings are carried out at some gun-tube elevation, the "vertical-up" position was chosen as representative of that configuration and is shown in Figure 2 with pressure gages and viewing block. The viewing block was designed to reduce the amount of smoke and flash between the camera and the primer and to minimize interference with functioning of the primer. High-speed photos were taken of the primer during firing. A more detailed view is given in Figure 3. The left-hand side is the view as seen from the camera. Two of the four rows of holes can be observed in this way. Several phenomena occur in making pressure measurements which cause irregular and irreproducible pressure-time curves:

1. wave dynamic effects caused by strong localized ignition,
2. unburned black powder ejected from the primer during combustion,
3. partial plugging of gage port by particulate matter.

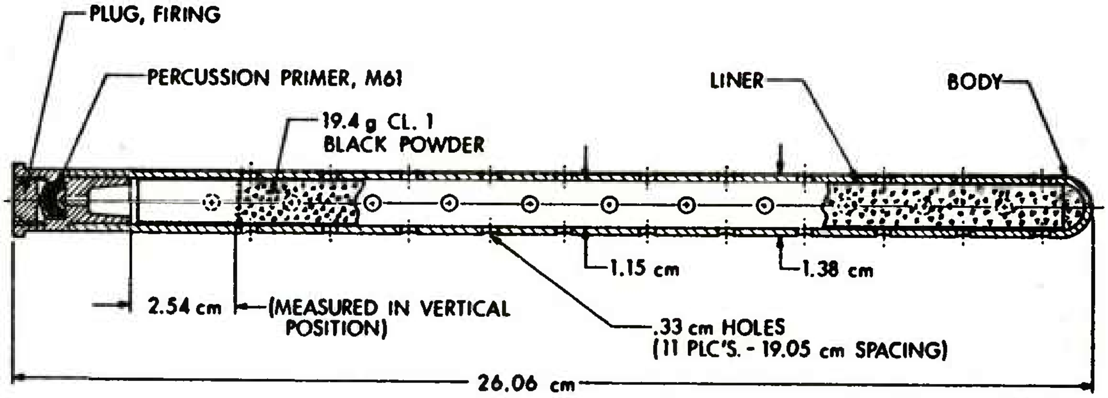

Figure 1. M28B2 Primer Used in 105-mm Howitzer

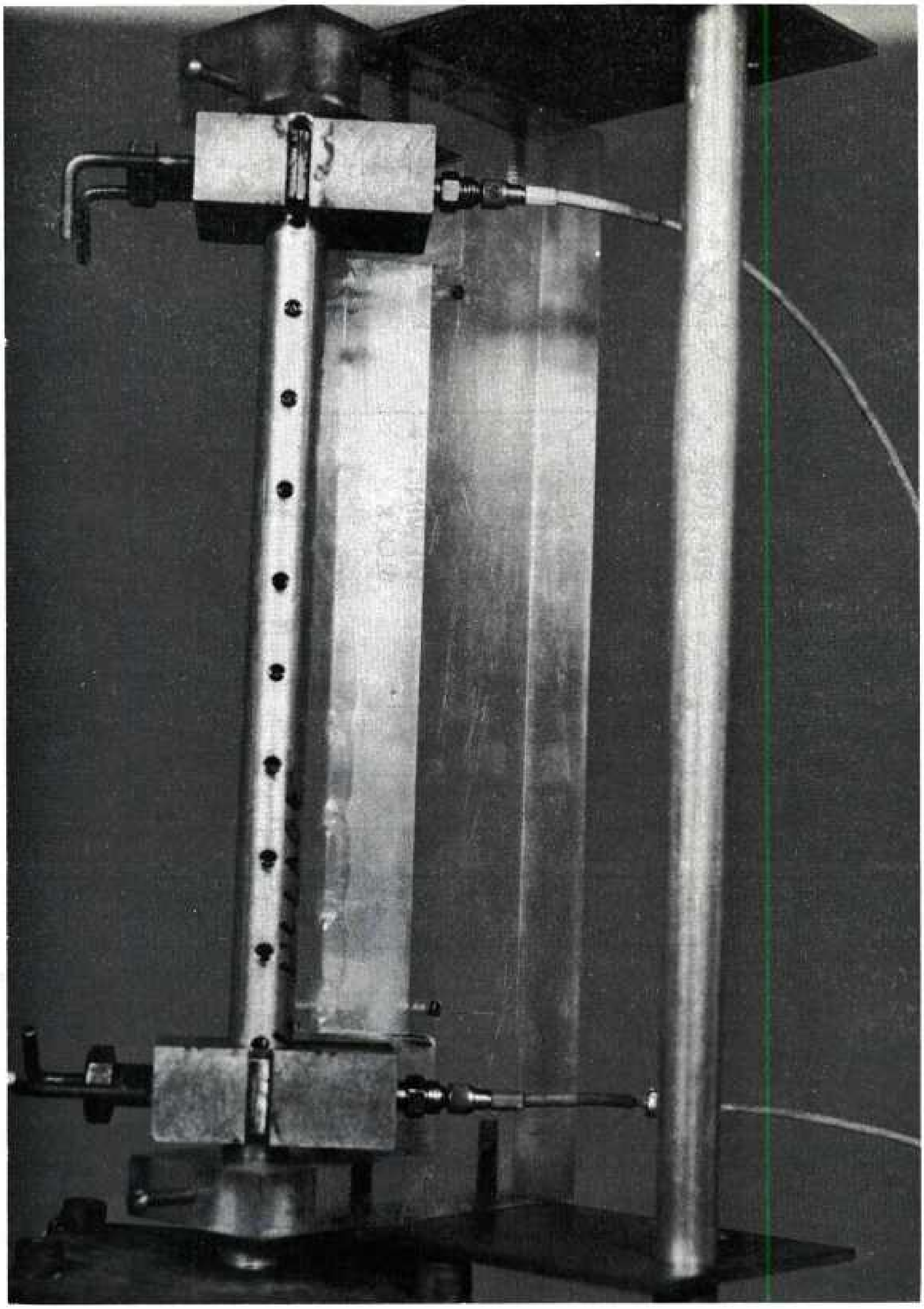

Figure 2. Photo of M28B2 Primer with Pressure Gage Adaptors and Plastic Viewing Block

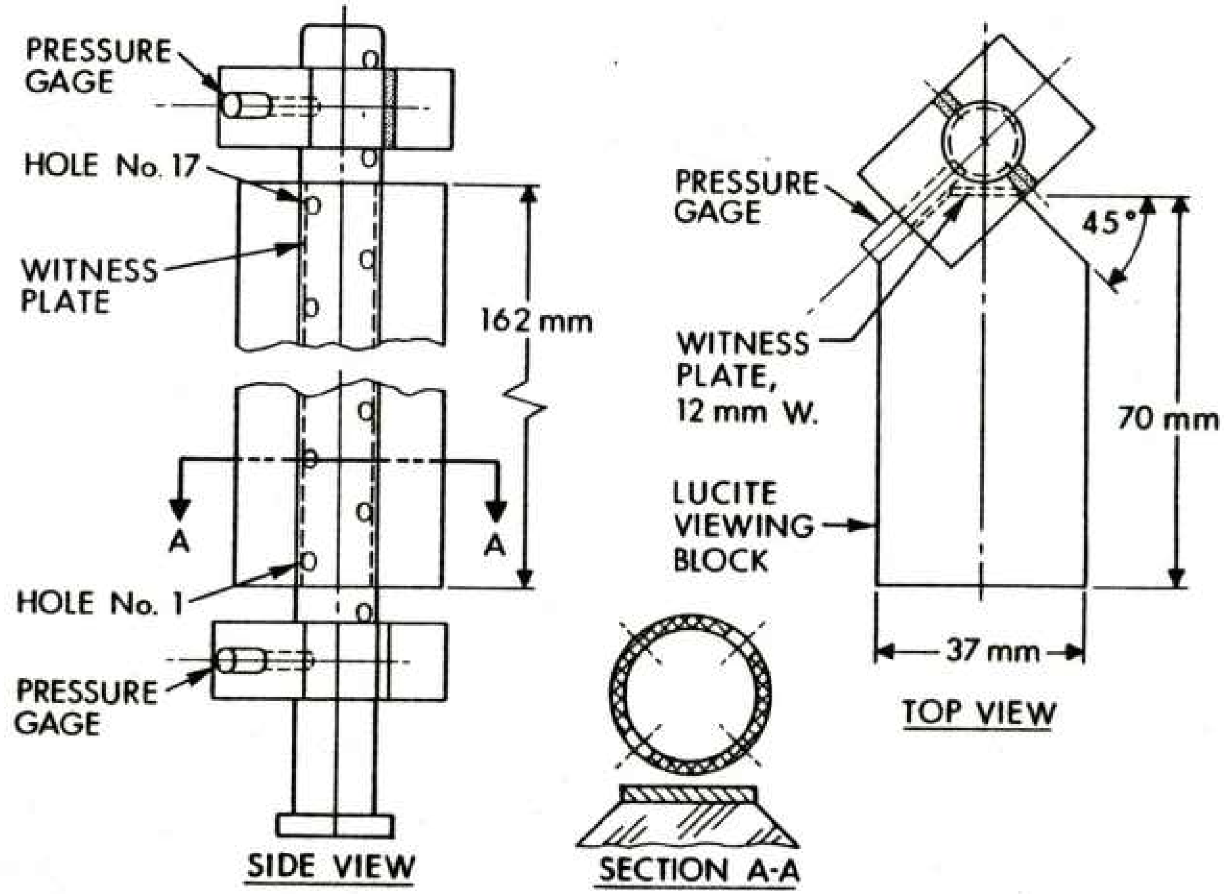

Figure 3. Schematic of M28B2 Primer with Viewing Block and Pressure Gages

Photographic data were analyzed in the following way. The time for appearance of the combustion flame at each observable hole was recorded. These data yielded a distance vs. time for the flame front as it moved down the primer tube and burned through the paper liner in the primer. An example of the pressure and distance vs. time curves is shown in Figure 4 for a fast black powder lot (Lot 11). A reasonably well defined flame-front velocity can be calculated from this curve. This illustrates pressure vs. time (——) and flame distance vs. time (oooo) for an M28B2 primer. The black powder used was deviant lot 11, high ash content.

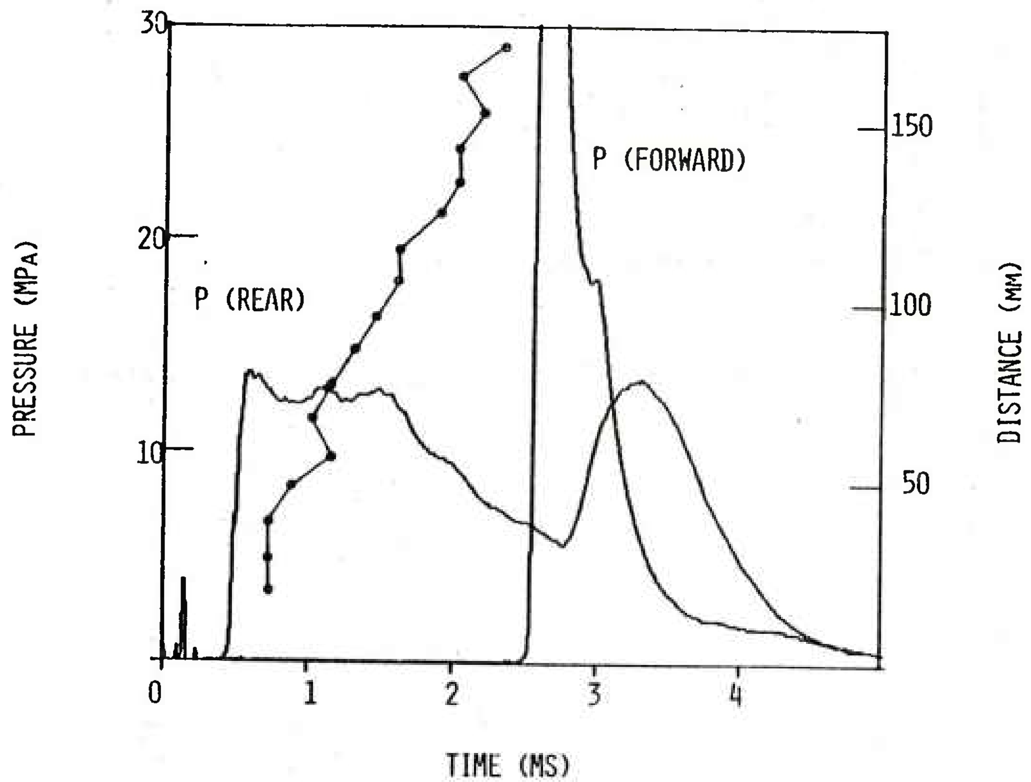

Figure 4. M28B2 Primer; Black Powder Deviant Lot 11, High Ash Glaze

Figure 5 illustrates pressure vs. time (——) and flame distance vs. time (oooo) for an M28B2 primer. The black powder used was deviant lot 5, low density. Note the low velocity out to 3 ms. It is seen that the velocity is not linear but starts out low and accelerates to a high value. Figure 6 illustrates pressure vs. time (——) for a M28B2 primer. The black powder used was deviant lot 7, high percent C. The flame distance vs. time for holes 1, 3, 5 is given by oooo and for holes 2, 4, 6 is given by xxxx. See Figure 3 for the location of the holes. Figure 6 shows

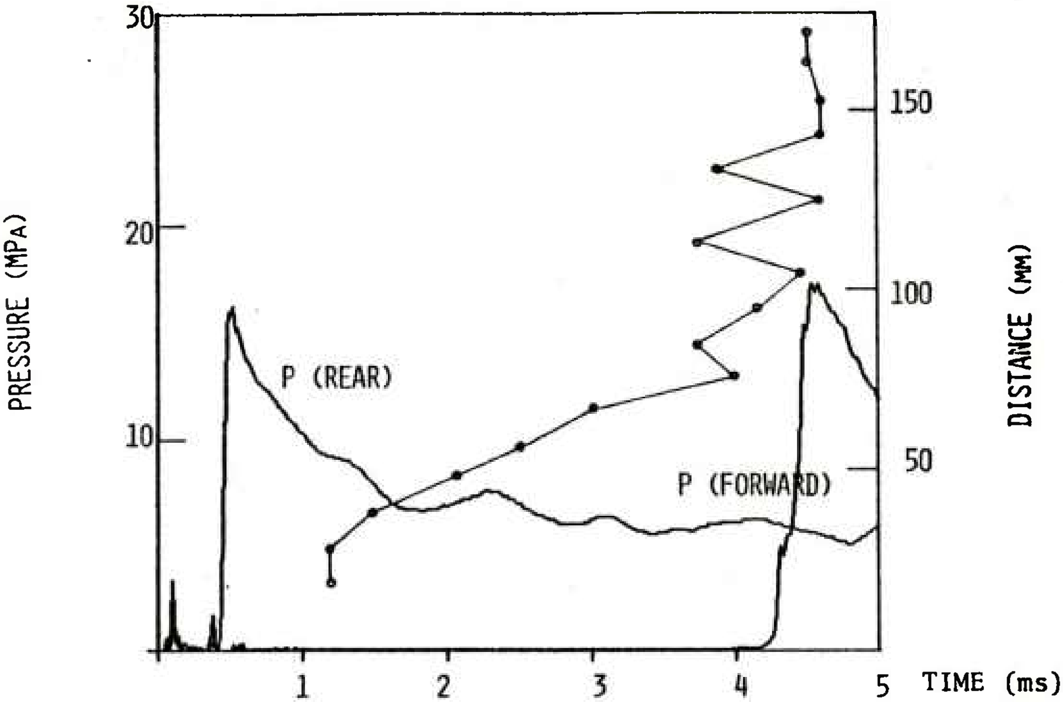

Figure 5. M28B2 Primer; Black Powder Deviant Lot 5, Low Density

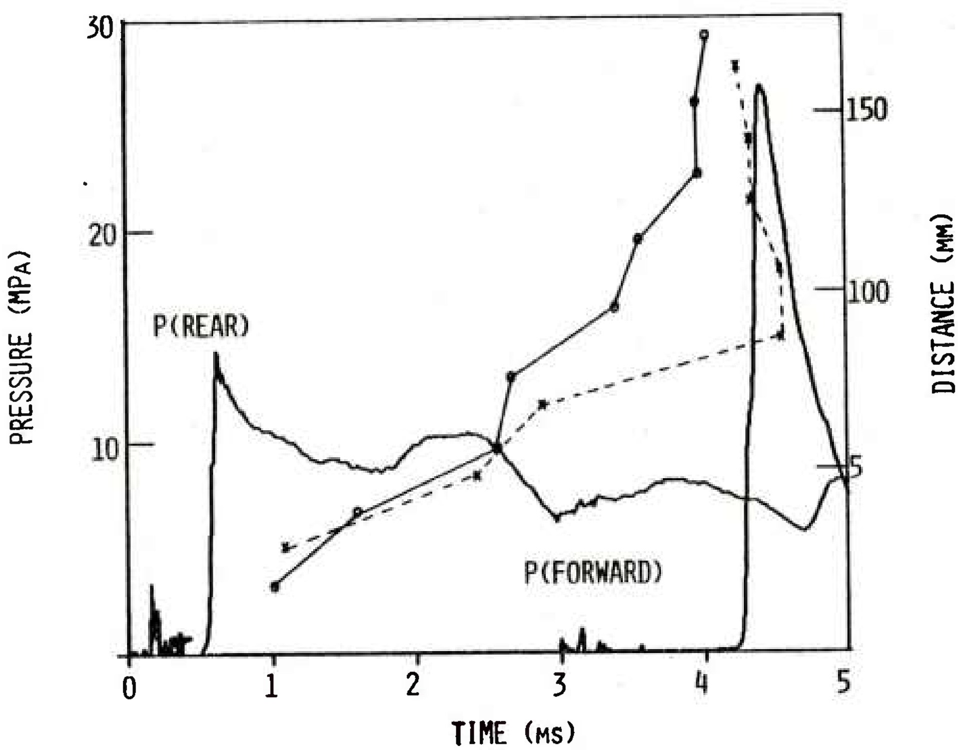

Figure 6. M28B2 Primer; Black Powder Deviant Lot 7, High Percent C

that the holes down one side of the tube open up much more rapidly than the other. The film also shows that when the pressure wave reaches the end wall [rise of $P_{Forward}(P_F)$] a substantial increase in luminosity is observed at the forward holes in the primer. Figure 7 gives the average propagation velocities for the twelve lots. The vertical bars on this and all other graphs indicate standard deviations. The propagation velocity was determined by measuring the time between the initial pressure rise of $P_{Rear}(P_R)$ and P_F and dividing that into the distance between the

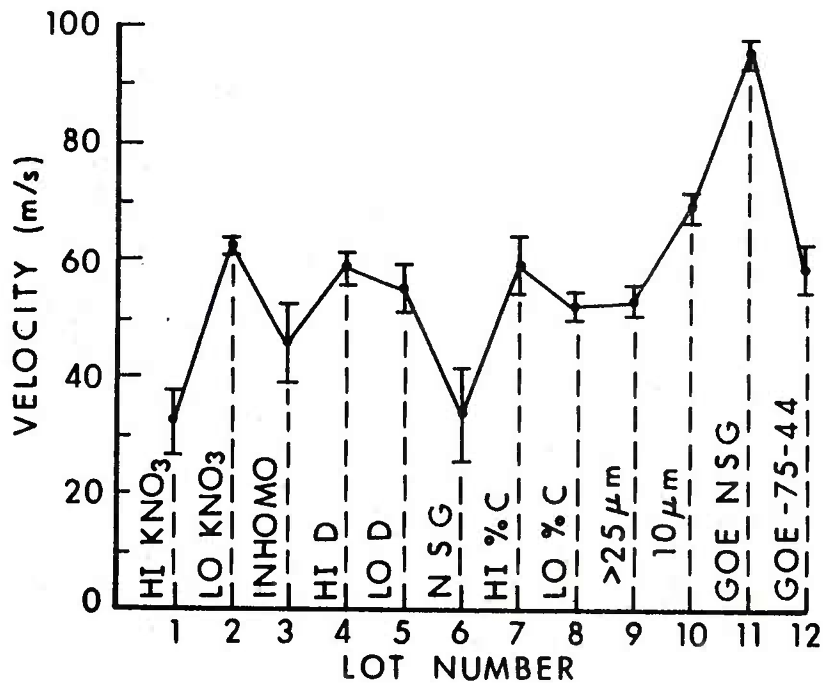

Figure 7. M28B2 Primer Propagation Velocity vs. Lot Number

holes. It is seen that there is more than a factor of three difference between the slowest and fastest lots. As has been explained and used by others[7], $\int P dt$ for both the rear gage (P_R) and forward gage (P_F) are proportional to the heat flow at these positions on the primer. These are shown for the twelve lots in Figure 8.

The purpose of a long primer, such as the M28B2, is to ignite the charge along the axis. Ideally, the ignition should be simultaneous along this axis, so as to avoid localized ignition in the propellant bed which is known to cause erratic ballistics in high loading-density charges.

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[7] *E. E. Ekstedt, D. C. Vest, E. V. Clarke, D. L. Wann, "Pressure Studies of Artillery Primers Fired Statically," Ballistic Research Laboratories, Report No. 938, June 1955.* (AD #77626)

Consequently, the primer propagation velocity and the forward and rear heat flows are used as figures of merit for this primer. From the standpoint of simultaneous ignition of the propellant bed, a primer should have a very high propagation velocity and a forward-to-rear heat flow ratio of 1.

It can be observed that most of the low-velocity lots have the largest $\int Pdt$. This is probably due to the fact that less unburned black powder is thrown out of the primer for the slower lots.

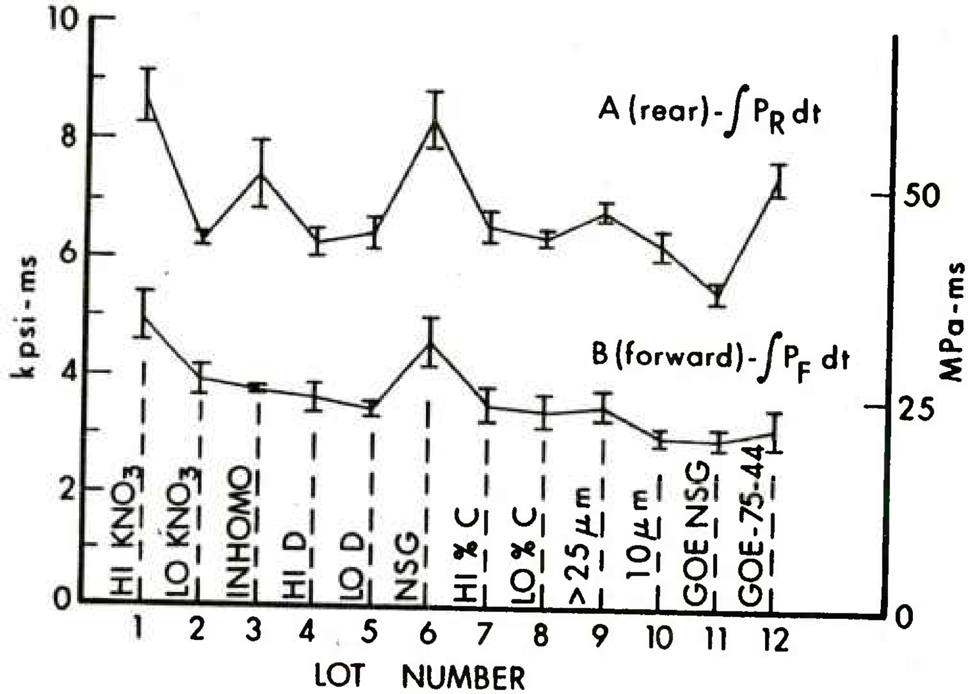

Figure 8. M28B2 Primer Heat Flow Integrals vs. Lot Number
$A = \int P(\text{Rear})dt$, $B = \int P(\text{Forward})dt$

Figure 9 shows the heat-flow ratio (Forward-to-Rear) for these lots. There do not appear to be any significant differences. The conclusions drawn from these tests are:

1. more unburned black powder is ejected from the faster burning lots,

2. the forward/rear heat-flow ratios are not substantially different for any of the lots,

3. the slower lots yield an erratic and slow flamespreading down the primer.

B. Low Pressure Igniter - M203 Charge

A black powder igniter system is used in the M203 top zone of a bagged charge employed in the 155-mm howitzer. It consists of a base-pad (28 g black powder) and a centercore snake (113 g black powder and a combustible nitrocellulose tube). The system is schematically shown in Figure 10. The deviant lots of black powder were loaded into the igniter system and the live propellant was replaced by inert propellant[6]. The charges were temperature conditioned to -53°C and fired in a chamber of dimensions similar to that of the howitzer. This low temperature condition was chosen as a "worst case" situation for this igniter system

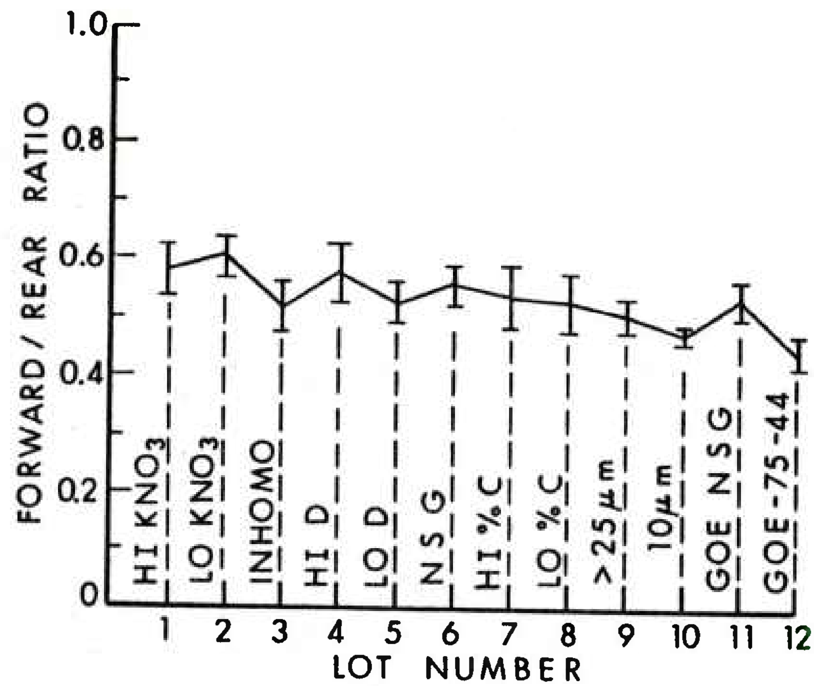

Figure 9. M28B2 Primer Heat-Flow Ratio: Forward/Rear vs. Lot Number

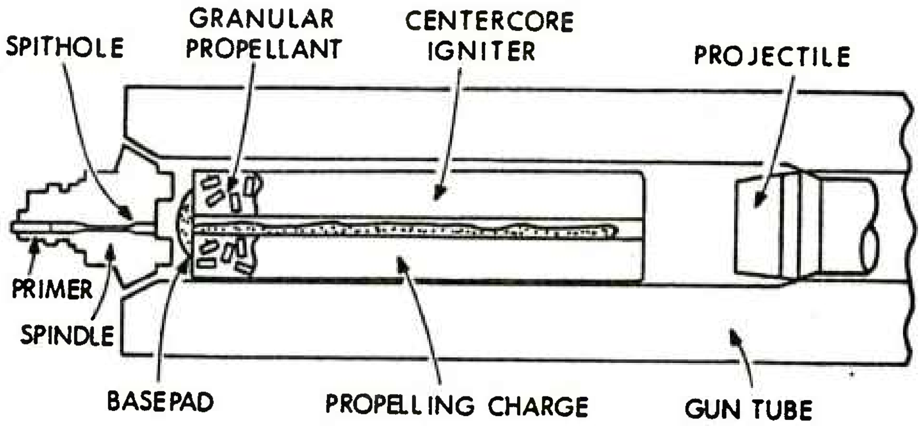

Figure 10. Schematic of M203 Charge in 155-mm Howitzer

since two hangfires have occurred under these conditions, one resulting in high pressures and damage to the cannon. The results for a few of the deviant lots (1, 6, 11, and 12) are shown in Table 2.

The conclusions that can be drawn from these tests are that the deviant lots have a substantial impact on the functioning of the centercore ignition system resulting in much longer action times and smaller dp/dt's for the slow lots.

C. Basepad Igniter - M2 Charge

The M2 charge is base ignited by a 142 g black powder igniter. This low loading-density charge is used in the 8-inch howitzer. It is similar to the charge shown in Figure 10 except that it does not have a centercore. Some test firings of two lots of black powder were carried out using the M2 igniter basepad and a 10-cm length bed of inert propellant in a chamber whose diameter was similar to that of the 8-inch howitzer chamber. Results of the firings are shown in Table 3. Again, a substantial difference in performance is noted between Lot 1 and Lot 11 with respect to dp/dt and action time.

TABLE 2. 155-mm HOWITZER SIMULATOR WITH M203 IGNITER*

LOT NO.	NAME	TIME TO PEAK PRESSURE ms	(S) ms	dp/dt max KPa/ms	(S) KPa/ms	TIME TO dp/dt max (ms)	(S) ms
1	DEV, High KNO_3	263	(49)	23	(6)	210	(80)
6	DEV, Nonstandard glaze	217	(47)	31	(3)	148	(30)
11	DEV GOE-75-44, Ash glaze	92	(9)	61	(11)	56	(6)
12	GOE-75-44	92	(7)	64	(10)	56	(4)
13	GOE-75-23	128	(21)	51	(10)	91	(18)
14	CIL-7-10	138	(20)	55	(8)	94	(18)
15	CIL-5-18	157	(10)	47	(2)	111	(13)

* Conditioning Temperature, -53°C
(S) = Standard Deviation

TABLE 3. 203-MM HOWITZER SIMULATOR*

	P_{max} (MPa)	TIME TO P_{max} (ms)	DP/DT KPa/ms	TIME TO DP/DT MAX. (ms)
Lot 1 High KNO_3	5.38 (.10)	70.5 (1)	159 (28)	31.3 (1)
Lot 11 GOE-75-44 High Ash Glaze	5.63 (.07)	38 (2)	318 (24)	11.8 (1)

*8.7-liter chamber with 0.575 liters of inert propellant
( ) - Standard deviation
M2 igniter, 142 g black powder basepad

A pressure-time curve for the M2 is seen in Figure 11. An induction period is observed in the early portion of the curve with a rapid increase at 9 ms and 0.35 MPa. This has been observed in a number of cases with a centercore igniter system[6]. Two other tests using Lot CIL 5-18 were carried out and the results are shown in Figure 12a and 12b for the M203 igniter system. Figure 12a shows the pressure-time curve for the case of the M203 igniter where the basepad has been removed (Figure 10). The abrupt change in pressurization rate is seen at approximately 100 ms and 0.2 MPa. Figure 12b shows the pressure-time curve for the "snake" only. For this configuration the basepad has been removed and the combustible centercore tube has been replaced by one made from a coarse wire mesh. A change in pressurization rate is observed at 180 ms and 0.3 MPa. This kind of change in gas generation rate has been seen by high-speed cinematography under somewhat different conditions. The "snake" appears to burn slowly at first and transits to a very rapid burn[6,8].

A number of other tests were devised in an attempt to find a simple explanation for the dramatic differences observed in the black powder lots. Additionally, it was thought that a correlation could be found between some property of the black powder and the ballistic performance.

[8] *T. J. Ohlemiller, "An Experimental Study of the Performance of Felted Nitrocellulose Igniter Tubes in an XM-198 Igniter Simulator," Guggenheim Laboratories, Princeton University, Prepared for Quality Assurance Directorate, USA., Picatinny Arsenal, New Jersey, February 1975.*

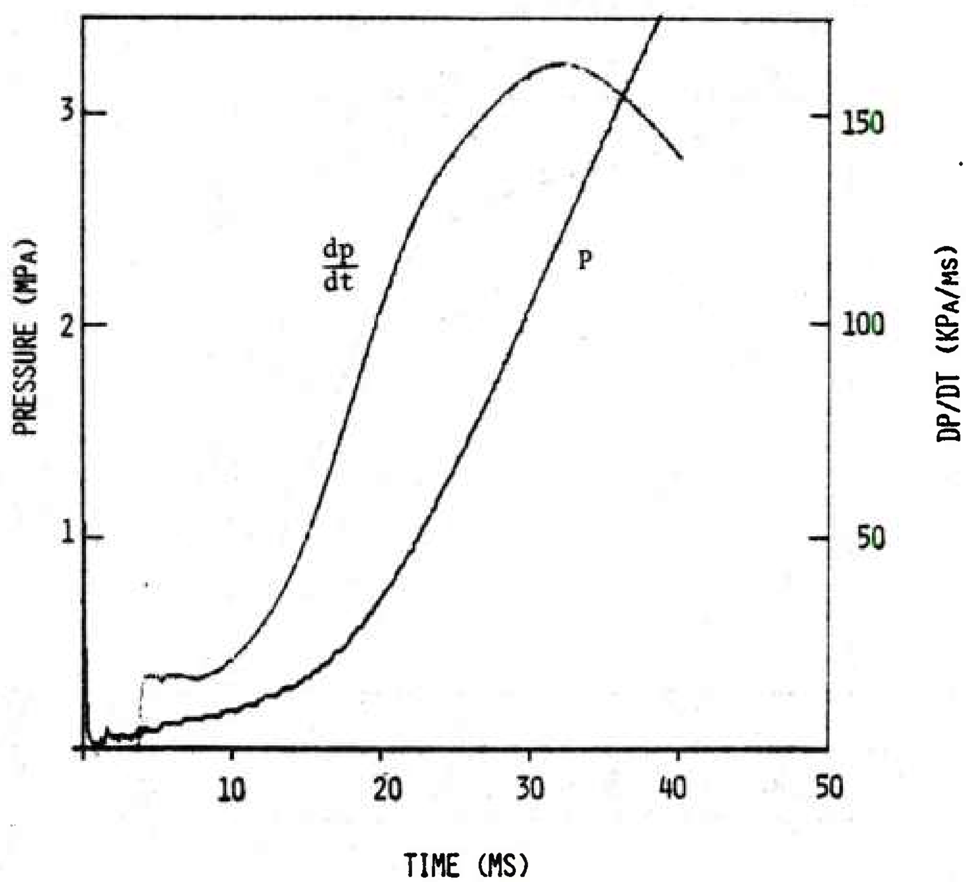

Figure 11. 203-mm Simulator with M2 Igniter: Black Powder, Lot 1, High KNO_3

D. Flamespread Tests and Moisture Analysis

Flamespread tests were carried out under unconfined conditions. Sixteen grams of black powder was spread out in a straight line, 460 mm in length and ignited at one end with a hot wire. Action time was monitored by a TV camera and the results shown in Figure 13. These include tests on Gearhart Owen (GOE) and Canadian Industries, Ltd. (CIL) black powder lots. The data were taken along with black powder dried for seven hours at 90°C. The percent water detected in this manner is given in Figure 14. Figure 15 shows the open-air flamespread velocities of the deviant lots along with several other sources: DUP - E.I. duPont de Nemours & Co., PA-I-1 - Italian powder; EGY - Egyptian Powder Co., PA-N-1 - Norwegian powder; APW - Austin Powder Co.; Cl-5 - class 5 black powder (0.4 - 1.2 mm), GOE 79-14. From the above tests we conclude the following:

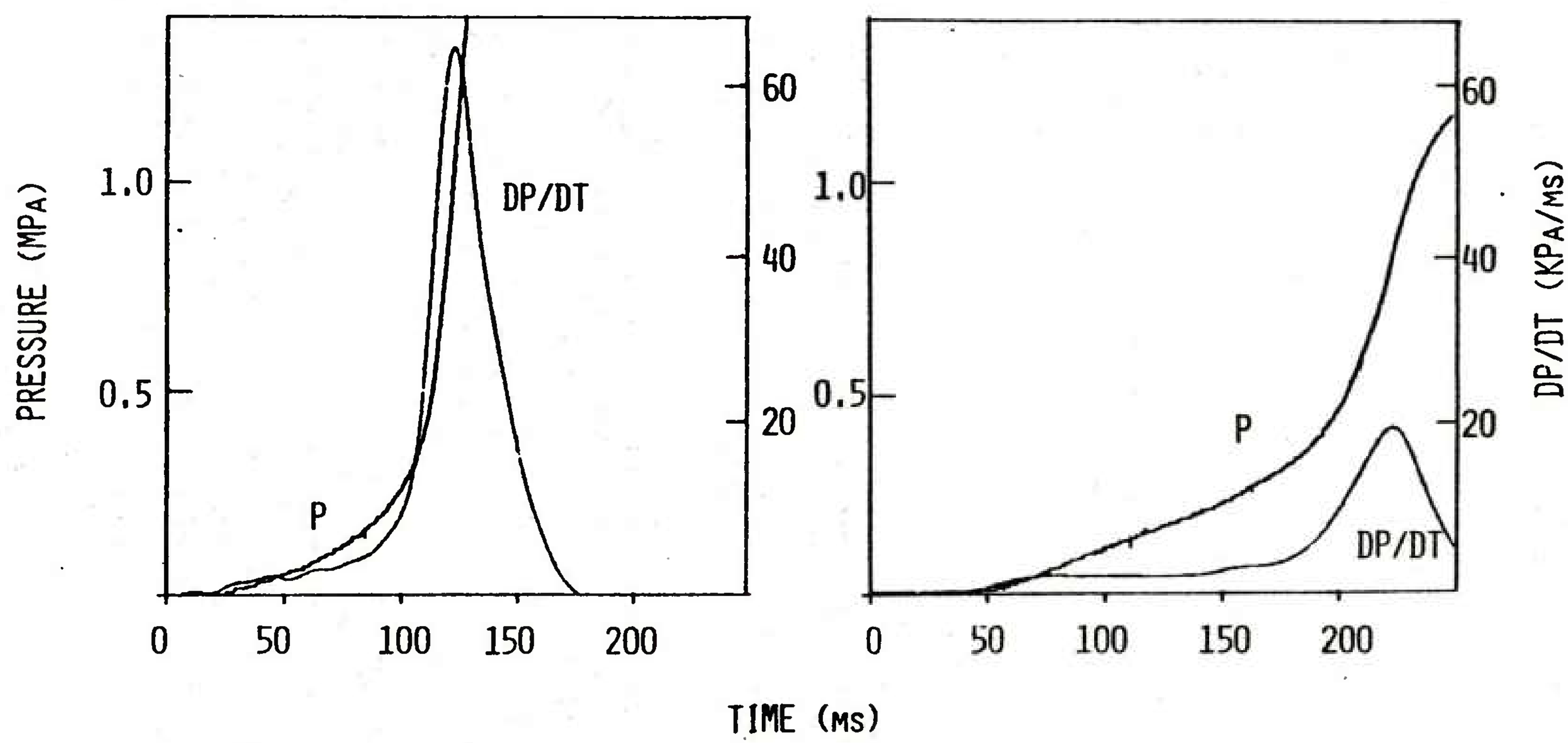

Figure 12. Modified M203 Igniter Fired in Simulator with a Soft Igniter (Electric Match)
(a) Igniter with Basepad Removed
(b) Igniter with Basepad and Combustible NC Tube Removed

1. The open-air, flamespread tests are qualitatively similar to those for the M28B2 tests, the closed bomb firings[4] and flamespread tests[5]. (Figure 16 gives the deviant lot normalized performance in the PCRL flamespread device (o) closed-bomb RQ (◘) and open-air flamespread configuration (Δ). All data are normalized to Lot 12 which is set equal to 100.)

2. Moisture content of most of the black powder as measured in this way is within the 1946[1] specifications. However, the fastest (Lot 11) is outside of the specifications.

3. Drying the black powder in this way did not substantially change the open-air flamespread rate.

4. In general, the deviant lots show a lower overall velocity than the conventional GOE or CIL lots.

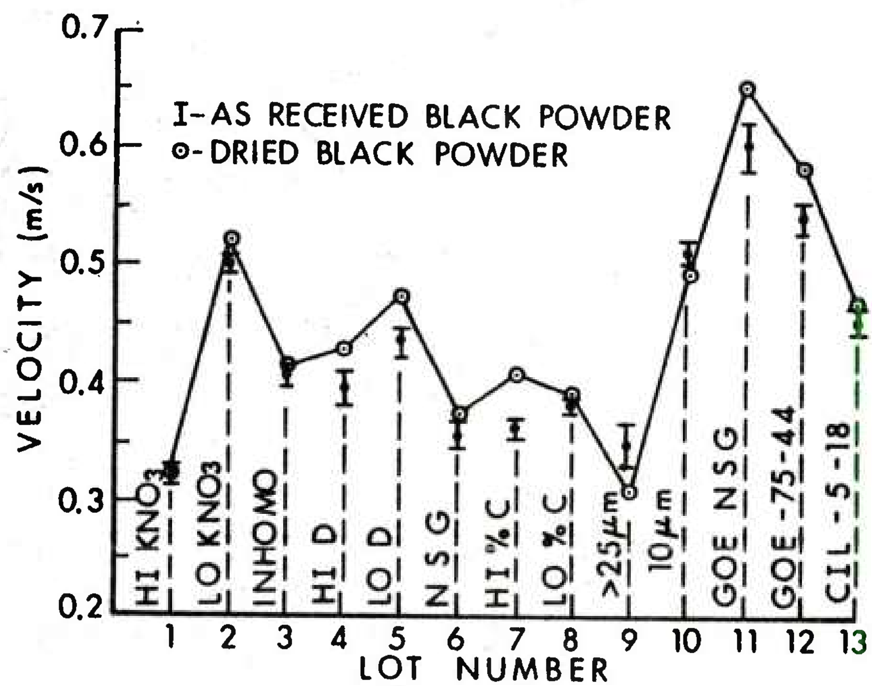

Figure 13. Black Powder Open-Air Flamespread Velocity vs. Lot Number

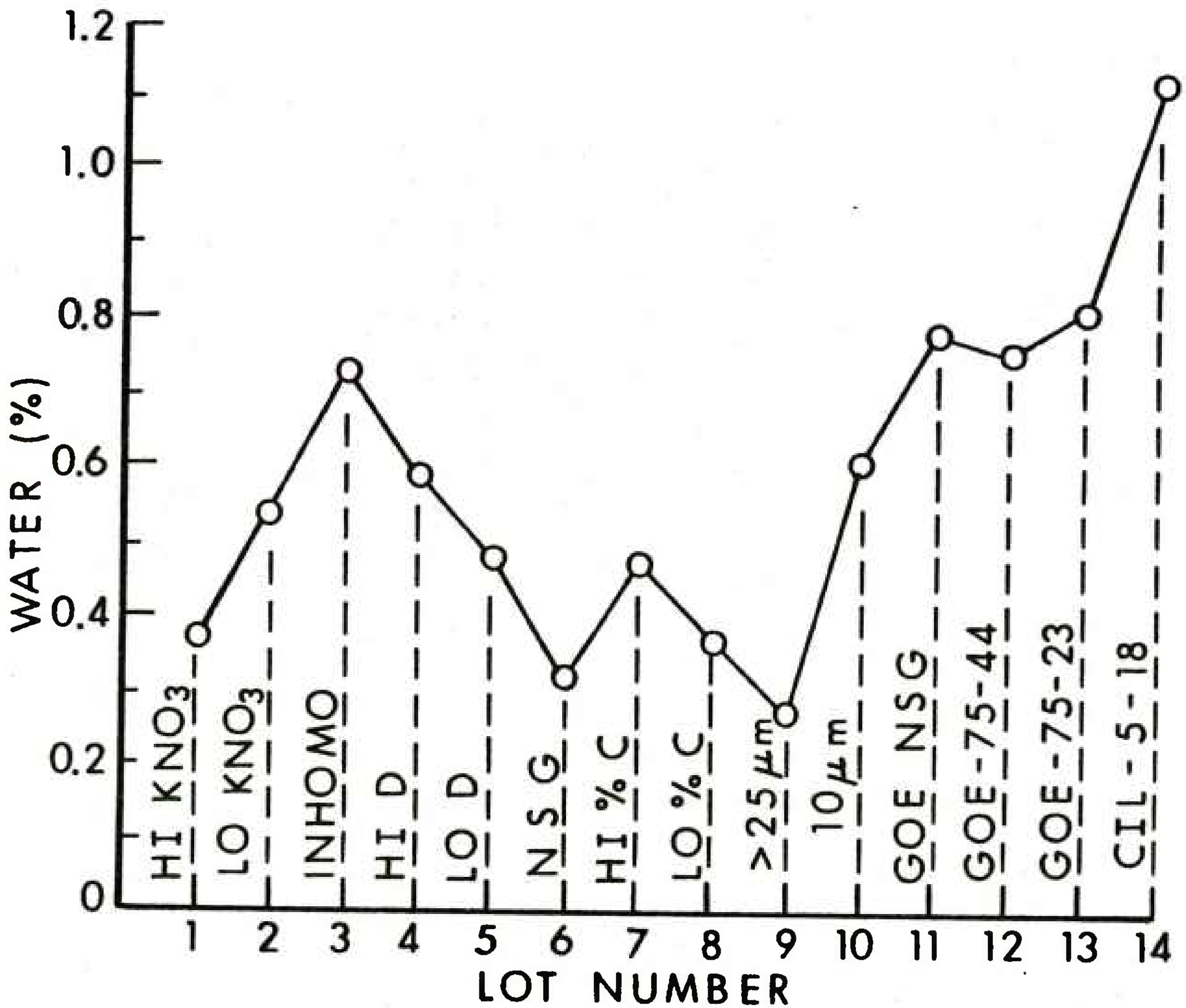

Figure 14. Moisture Content of Deviant Lots of Black Powder

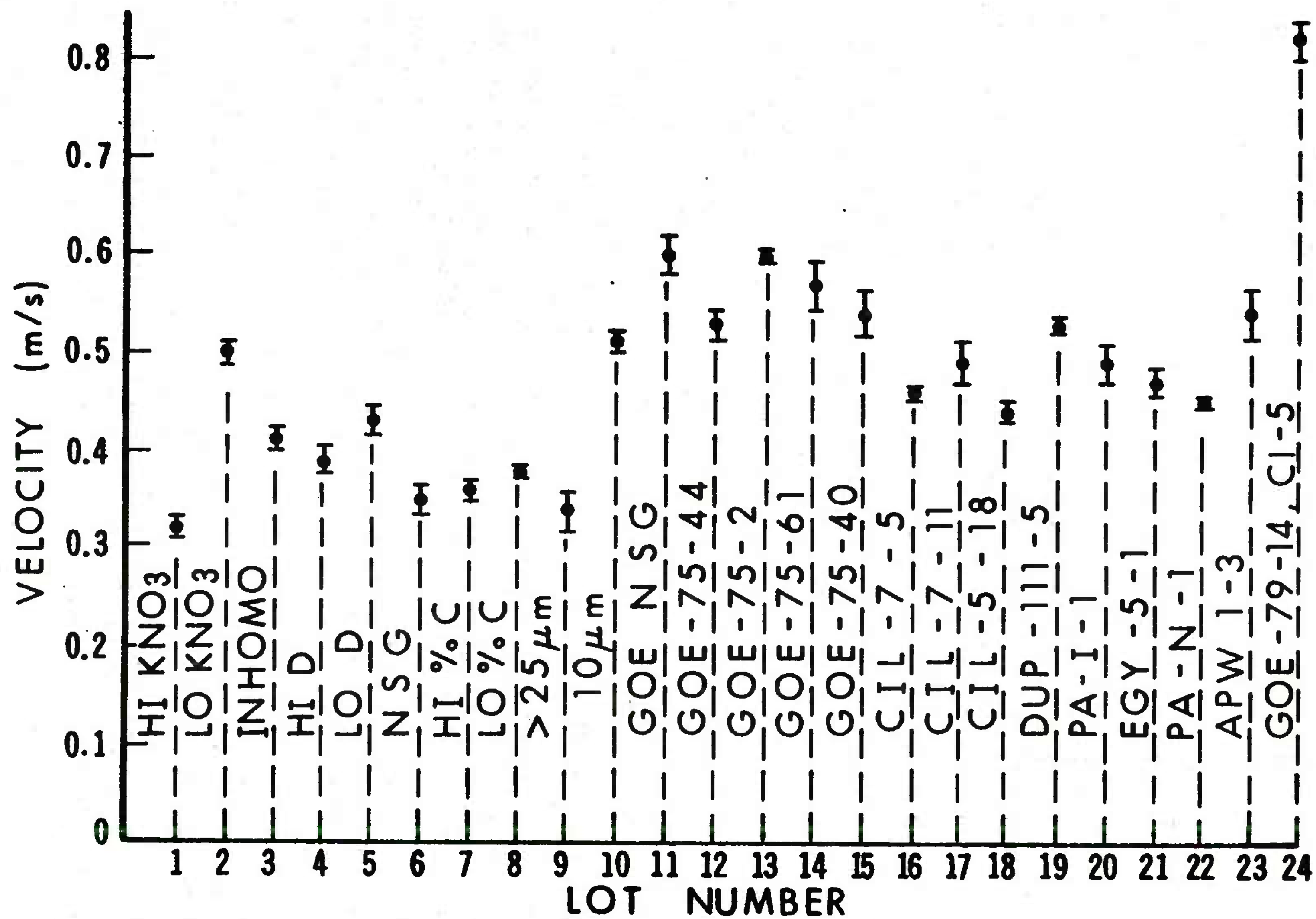

Figure 15. Open-Air Flamespread Velocities for Black Powder

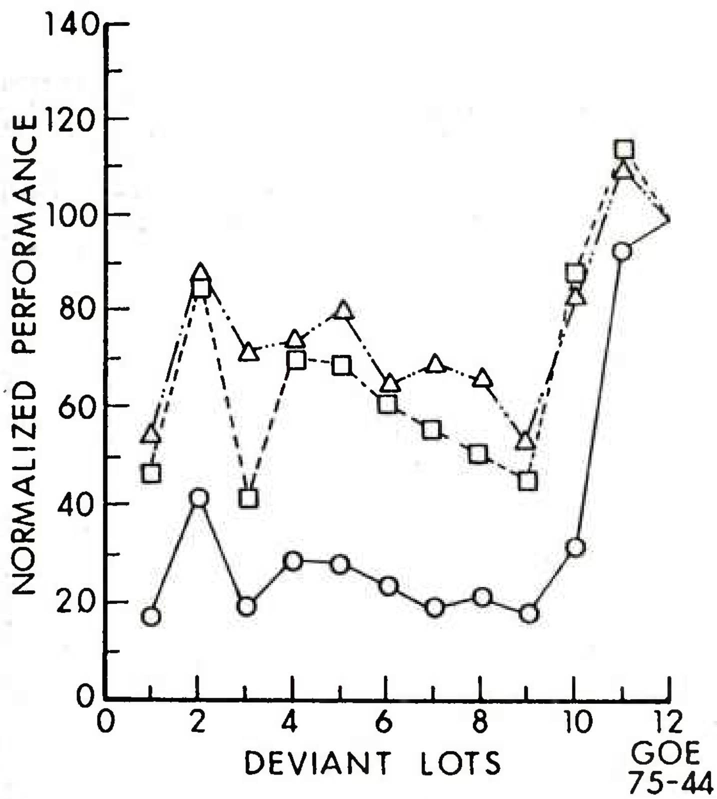

Figure 16. Deviant Lot Performance

E. Surface Irregularity

Could the differences in lots be due to surface irregularity in which the heat-transfer characteristics would be different from one lot to another? This is a difficult question to answer and would involve a detailed measurement of surface characteristics along with some statistical averaging. Visual examination of Lot 1 showed that the grains were very smooth and regular. Grains from Lot 6 were very irregular in shape, with many sharp edges. These lots were both slow in their performance indicating that heat-transfer characteristics due to surface roughness cannot be the dominant factor.

F. Bed Packing Density

Is it possible that different grain shapes and sizes could cause a different packing density and bed porosity leading to a different flame-spread rate? To answer this, 56 g of each lot was loaded into a 25-ml cylinder and the length measured. The results are given in Figure 17.

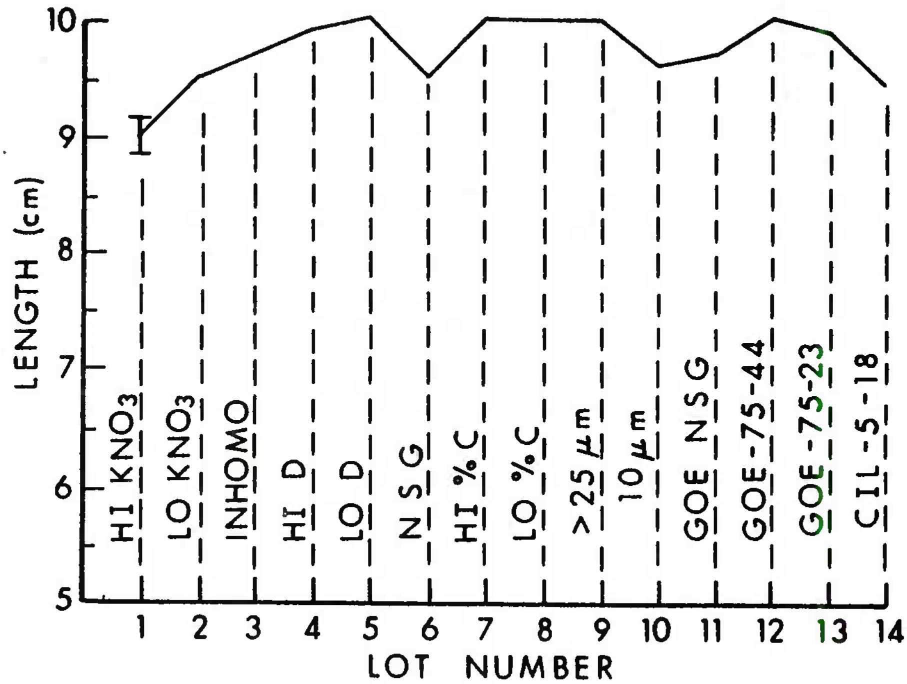

Figure 17. Loading Length of 20 g of Black Powder in a 25-ml Cylinder

There does not appear to be any correlation between loading length and performance, hence the porosity of the beds cannot be a dominant factor explaining the ballistic differences.

G. High-Speed Cinematography

The next aspect of this investigation was to see what role was played by the ignition and combustion of the black powder itself. Individual grains were ignited by a rapidly heated wire in the open air and were photographed by high speed cinematography. Lots 1, 6, and 11 were photographed along with some conventional lots, GOE 75-61, GOE 75-2, CIL 5-18, and CIL 7-10. The sequence of events in the ignition and combustion process as seen from the films can be described as follows:

1. A short "puff" of hot gas was observed to come from the grain as the wire heated the surface. This was clearly seen using infrared-sensitive films.

2. The formation of smoke followed this event.

3. A black liquid droplet was seen to form where the hot wire made contact with the grain. This droplet grew in size and eventually began to glow.

4. Upon full ignition-

   a. The glowing liquid droplets came off of the regressing surface. In fast-burning lots very few large droplets were formed.

   b. Under these ambient conditions the flame did not spread over the surface of the grain but burned "cigarette" fashion.

   c. After a substantial portion of the grain had burned there appeared to be a transition to a more vigorous burning mode producing a great deal more flame luminosity.

Repeating the most important observation, the slow-burning lots (1, 6, and CIL 5-18) formed large quantities of glowing droplets whereas the faster lots (11, GOE 75-61) burned cleanly with little evidence of droplet formation. Typical results from Lot 1 and GOE 75-61 are seen in Figure 18. This picture, using strobe lighting, illustrates the flame produced by lot GOE 75-61 (left) and deviant lot 1 (right). The framing rate used was 5100 pps. The markers in the photo are 1/2-mm wide.

H. Hot-Wire Ignition Tests

The ignition characteristics of Lots 1 and 11 were studied by igniting samples (10-50 μg of ground black powder) on a hot-wire pyrolizer.[9] The samples were heated at various rates and the ignition was defined as the time at which there was a sudden emission of light. The appearance of light was very rapid compared with the heating rate under all conditions tested here. The results are given in Table 4 for Lots 1 and 11. The difference in time to ignition is not very large at the lower heating rates but increases at the highest heating rate. Even here the difference is small when compared with the differences noted in the various igniter systems for Lots 1 and 11. (Figure 16). However, the tests could reflect a cumulative effect of a change in ignition delay since the M203 and M28B2 igniters involve flamespreading. The conclusion that can be drawn from this preliminary work is that the ignition characteristics measured by hot-wire ignition for the two lots tested show the same qualitative trend but are quantitatively quite different from that found in the igniter tests.

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[9] *A. Beardell and J. Staley, "High Heating Rate Thermal Decomposition of Nitrocellulose," P. 51. J. Rocchio and R. Wires, "The Effect of Heating Rate on the Thermal Decomposition of Propellant Ingredient," p. 77, in E. Freedman and K. J. White, eds., "1975 Annual Review of the ARMCOM Program, The Fundamentals of Ignition and Combustion," Ballistic Research Laboratory Report 1883, May 1976.* (AD #B011644L)

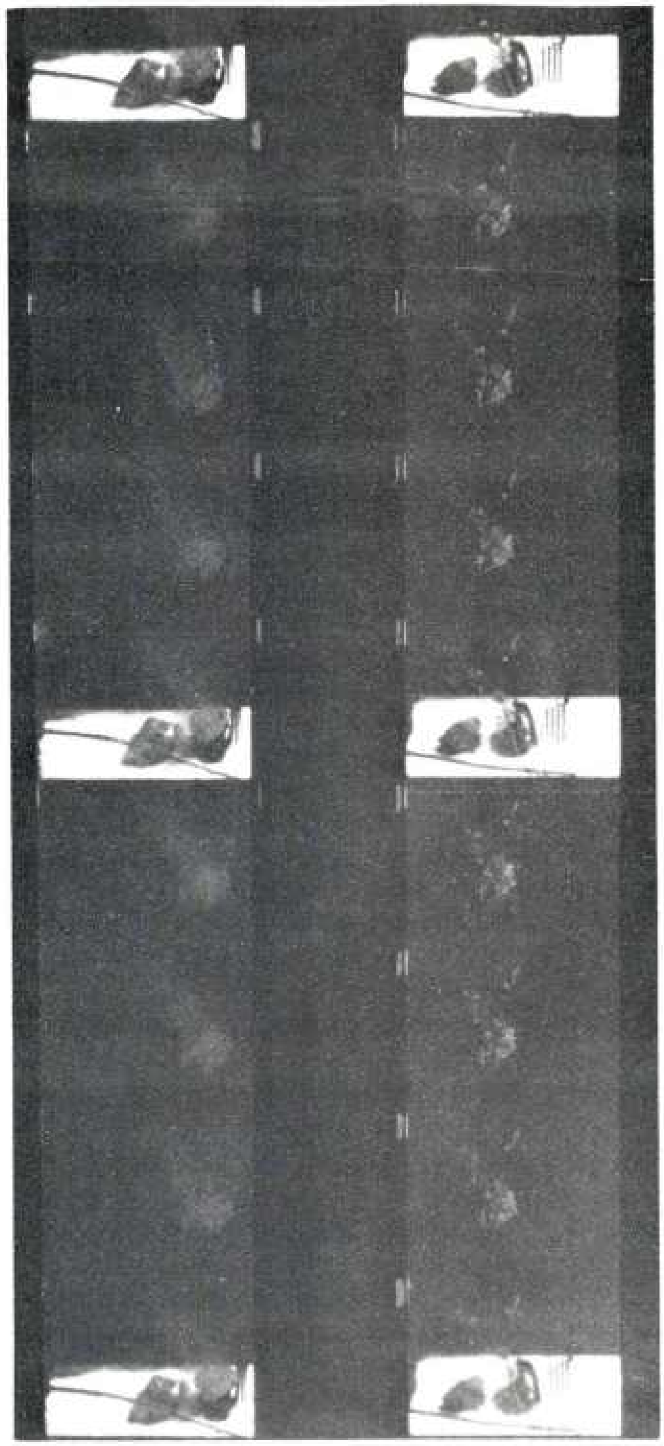

Figure 18. High Speed Cinematography of Lot GOE 75-61
(Left) and Deviant Lot 1 (Right)

TABLE 4. HOT-WIRE IGNITION DELAY TEST; DEVIANT LOT 1 AND DEVIANT LOT 11

HEATING RATE* (°C/ms)	IGNITION DELAY (sec) Lot 1	Lot 11
21	0.136 (.021)	0.086 (.008)
1.75	0.510 (.030)	0.457 (.011)
0.63	1.123 (.015)	1.003 (.006)
0.24	2.50 (.043)	2.30 (.050)

*Final temperature 840°C
( ) = Standard deviation

The information presented in this section is mostly preliminary and was carried out to see if some very obvious factor caused the differences in the performance of the various lots, and to help determine areas for future work on black powder. The most important conclusion from all of these tests is that there can be significant variations in the performance of igniter systems and this is due to the mode of combustion of the black powder. The high-speed films of the burning grains show significant differences in the way black powder burns. More work is required in determining the gas phase temperature of the burning black powder and identifying the nature of the droplets formed in the burning process.

III. DISCUSSION

Ballistic firings in several other programs have shown the potentially dangerous situation that can be induced in the M203 charge by using a relatively slow-burning black powder. The same cannot be said with respect to the M28B2 primer in the 105-mm howitzer. At this point, we do not know if there is or is not an unacceptable ballistic variability in this howitzer when using slow black powder. We must establish the relationship between the flamespreading velocity down the primer tube and the flamespreading velocity in the propellant bed. If the latter is much greater than the former then slow-burning lots may not have any ballistic effect. The flamespreading in the bed will dominate the ignition event. If, however, the primer-tube flamespreading velocity is larger, then differences in black-powder lots could have a significant impact on ballistic performance.

Similarly, we do not know the ballistic significance of the performance of the M2 charge in the 8-inch howitzer with the different lots.

It should be pointed out that because of clogging problems[10] the deviant lots made by the pilot plant jet-mill did not employ as much moisture as the wheel-mill procedure. The role of moisture in the mixing process and its effect on ballistics must be established.

Figure 16 is a summary of data from the LCWSL closed bomb firings[4] and the PCRL flamespread device[5] along with the open-air flamespread tests. All data were normalized to the arbitrary standard Lot 12, GOE 75-44. The closed bomb results were evaluated with respect to the relative quickness (RQ). Qualitatively, the trends from all devices were similar although there were some quantitative differences. Figure 19 shows the deviant lot performance in the PCRL flamespread device (o) closed-bomb RQ (□) and M28B2 primer (▽). All data are normalized to lot 12 which is set equal to 100. The trends are again mostly in agreement although

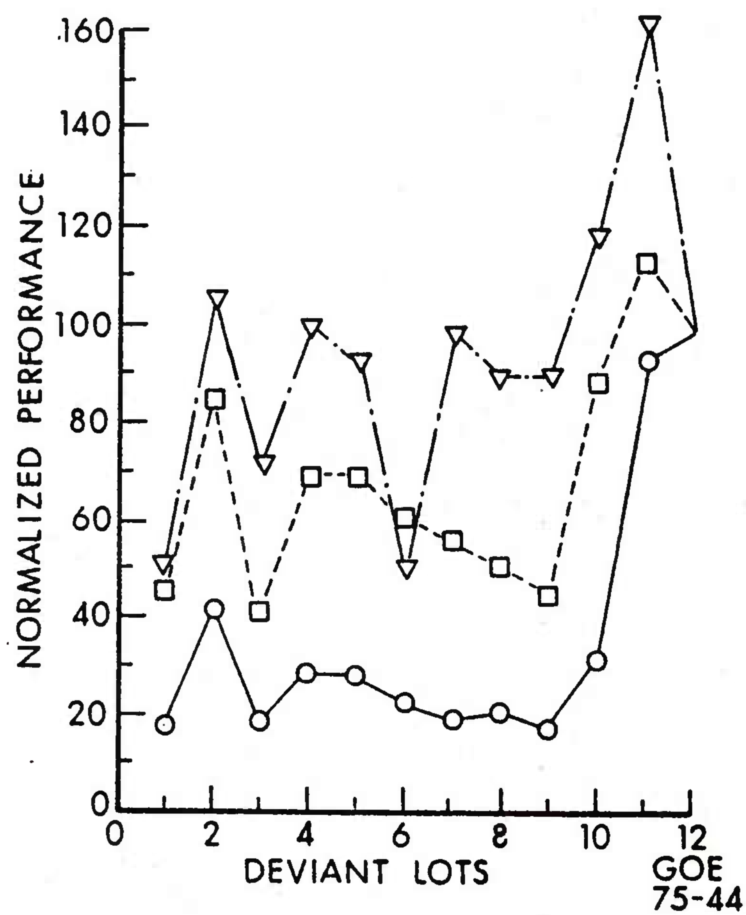

Figure 19. Deviant Lot Performance

[10] *"Acceptance of Continuously Produced Black Powder," Contractor's Report, Indiana Army Ammunition Plant, March 1979 (to be published).*

there is one major exception for the M28B2 primer. The standard Lot 12, GOE 75-44 is more comparable to the deviant-lot performance in the M28B2 than in the other devices.

Three of the test devices show black powder flamespread characteristics under quite different conditions, as is seen in Table 5. The observed pressure in the PCRL device was lower than in the primer.

TABLE 5. COMPARISON OF FLAMESPREAD MEASUREMENTS

Device	Pressure	Velocity Range
Open air flamespread	0.1 MPa	0.3-0.7 m/s
PCRL flamespread	3.5-10 MPa	8-40 m/s
M28B2 primer	10 MPa	30-100 m/s

Furthermore, ignition of the M28B2 was carried out by a more vigorous igniter than the PCRL device. The M28B2 primer has an ullage of several tens of millimeters (Figure 1) whereas the PCRL device had none. These different operating conditions could account for some of the quantitative differences in results.

If one looks at only the deviant lots and attempts to group them, then Lots 1, 3, and 9 could be considered "slow" and Lots 2 and 10, "fast". The "slow" lots are, respectively, high KNO_3 content, poor agglomeration or mixing of the ingredients and large particle size. The "fast" lots include low KNO_3 content and small particle size.

Of equal interest is the observation that Lots 4 and 5 (Figure 16) were not substantially different in performance as measured by all three techniques. These lots represent "low" and "high" density black powder. However, this result should be viewed cautiously for two reasons. Firstly, Lot 4 was not especially "high" in density. In fact, Lot 1 had a higher density (Appendix). Additionally, Lot 10 had a lower density than Lot 5 (Appendix).

It is also noted that Lots 7 and 8 do not show big differences in performance. Lot 7 was made from charcoal with a percent fixed carbon of 79.7 percent and Lot 8 of 61.6 percent. Hintze's[3] results indicate that the more dramatic ballistic changes are observed when the carbon content changes from 65 percent up to 80 or even 85 percent. However, we do not know if this percent carbon is based on a moisture and ash-free basis, hence comparisons are difficult to make. Also, oak charcoal was used in the deviant lots whereas maple was used in the GOE and CIL lots. Reference to Figure 16 and Table 6 should emphasize the fact that the deviant lots have generally lower performance than "conventional" lots. However, some of the lots (2 and 10) are comparable to the CIL lots containing maple charcoal, hence the different charcoals cannot account completely for the differences. Moreover, Lots 1 and 2, 9 and 10 all used the same charcoal and they show substantial differences in performance. One can conclude from this that there is a hidden variable in the manufacturing process that is causing substantial differences in the combustion properties of black powder. R. Sasse[11] has recently been working on this problem and has found a correlation between burn rate and internal surface area or "openness" of the black powder grains.

TABLE 6. BLACK POWDER CLOSED BOMB RESULTS FROM L. SHULMAN[4], LCWSL

LOT	RELATIVE QUICKNESS (based on CIL 7-3)
CIL 7-3	100
CIL 7-6	95.2
CIL 7-10	99.1
CIL 7-11	88.3
GOE 75-2	107.7
GOE 75-7	131.1
GOE 75-14	121.9
GOE 75-24	117.0
GOE 75-32	129.8
GOE 75-40	148.3
GOE 75-44	149.3
GOE 75-53	149.5
GOE 75-61	162.6
DEVIANT #1 (High KNO_3)	67.2
DEVIANT #6 (Non-standard glaze)	89
DEVIANT #11 (GOE, High ash glaze)	156.8

[11] *R. A. Sasse', "Influence of Physical Properties of Black Powder on Burning Rate," Seventh International Pyrotechnics Seminar, Vol. 2, pp. 563-584, July 1980.*

IV. CONCLUSIONS

1. Black powder combustion differs substantially from lot to lot.

2. There appears to be a slow and a rapid gas generation rate with a transition from slow to rapid occurring at low pressure. These could be related to flamespread rates.

3. Conclusions 1 and 2 have an impact on the functioning of igniter systems.

4. A hidden variable exists in the manufacture of black powder that affects performance.

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APPENDIX

ANALYSIS OF BLACK POWDER

ANALYSIS OF BLACK POWDER*
PROJECT 5764303

Twelve (12) samples of black powder, eleven (11) deviant lots manufactured in the pilot plant and one (1) control lot manufactured by GOEX, were analyzed in accordance with the military standard MIL-P-223B. Listed below are the results of all tests. Percentages indicate allowable range.

LOT NO.	MOISTURE	POTASSIUM NITRATE	SULFUR	CHARCOAL	ASH	SPECIFIC GRAVITY (gm/cm^3)	GRITTY/ PARTICLES
	0.60% Max.	73.0%-75.0%	9.4%-11.4%	14.6%-16.6%	0.80% Max.	Glazed 1.72-1.80 Unglazed 1.69-1.76	None
1**	0.22%	78.01%	8.50%	11.95%	1.90%	1.86	None
2**	0.87%	73.00%	10.40%	16.30%	1.20%	1.74	None
3	1.08%	75.90%	9.24%	13.01%	2.98%	1.77	None
4**	0.91%	74.81%	9.29%	16.05%	1.77%	1.80	None
5**	0.30%	74.94%	9.07%	14.44%	1.86%	1.67	None
6	0.55%	74.88%	9.23%	14.08%	2.37%	1.78	None
7	0.24%	74.52%	10.13%	15.21%	2.30%	1.67	None
8	0.80%	75.00%	10.23%	13.86%	1.35%	1.70	None
9	0.70%	72.50%	10.97%	13.59%	3.66%	1.70	None
10	0.73%	74.60%	10.38%	14.02%	1.47%	1.63	None
11	0.39%	74.29%	10.06%	15.56%	0.48%	1.67	None
12***	0.35%	74.05%	10.18%	15.38%	0.78%	1.72	None

ANALYSIS OF BLACK POWDER (Cont.)
PROJECT 5764303

* "Acceptance of Continuously Produced Black Powder," Contractor's Report, Indiana Army Ammunition Plant, March 1979, (to be published).

** NOTE: Target composition for these lots differ from MIL-P-223B. They are as follows:

Lot 1: 77% Potassium Nitrate; 13.8% Charcoal; 9.2% Sulfur
Lot 2: 71% Potassium Nitrate; 17.4% Charcoal; 11.6% Sulfur
Lot 4: Glazed specific gravity greater than 1.80
Lot 5: Glazed specific gravity less than 1.70

*** Lot 12 was GOE-75-44.

CHARCOAL CLASS A, JAN-C-178

Sample Identification Specification Requirements	Moisture % 5% Max	Ash % 5% Max	% Fixed Carbon None	% Fixed Carbon* None
Specification Charcoal Results	6.2	8.1	63.27	73.8
High-Carbon Charcoal Results	6.0	8.9	67.79	79.7
Low-Carbon Charcoal Results	6.5	8.2	52.58	61.6

* Moisture and ash-free basis

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